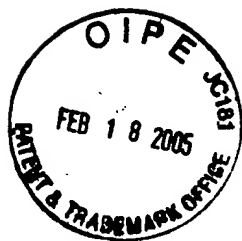# MARKED-UP SPECIFICATION

TITLE: METHOD AND APPARATUS FOR REDUCING THE WORD
LENGTH OF A DIGITAL INPUT SIGNAL, AND METHOD AND
APPARATUS FOR RECOVERING THE DIGITAL INPUT SIGNAL

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SERIAL NO.: 09/938,378

ATTY. DOCKET NO.: PHNL 000467

METHOD AND APPARATUS FOR REDUCING THE WORD LENGTH OF A DIGITAL INPUT SIGNAL, AND METHOD AND APPARATUS FOR RECOVERING THE DIGITAL INPUT SIGNAL

BACKGROUND OF THE INVENTION

Field Of The Invention

[0001]   The present invention relates to a method for reducing the number of bits of a digital input signal, comprising the steps

5   of adding a pseudo-random noise signal to the digital input signal to obtain an intermediate signal, the pseudo-random noise signal being defined by noise parameters, and ~~quantising~~ quantizing the intermediate signal, having a word length of n bits, to a reduced ~~word~~ word-length signal, having a word length of m bits, n being

10   larger than or equal to m. In a further aspect, the present invention relates to a signal processing apparatus, comprising a pseudo-random noise generator for generating a noise signal being defined by noise parameters, an addition element connected to the noise generator for adding the noise signal to a digital input

15   signal to provide an intermediate signal, and a first ~~quantising~~ quantizing element connected to the addition element for transforming the intermediate signal, having a word length of n bits, into a reduced ~~word~~ word-length signal, having a word length of m bits, n being larger than or equal to m.

20

Description Of The Related Art

[0002]   British ~~patent~~ Patent ~~application~~ Application No. GB-A-2
293 297 describes an apparatus for processing an input digital
signal with a word length of 32 bits to generate an output digital
signal of a lower resolution (16 bits). Before converting the
5   digital signal to an output digital signal with the lower
resolution, pseudo-random noise is added to the input digital
signal. Adding the noise results in a dithering of the signal, in
order to smooth out the harsh linear transfer function of the 32-
bit to 16-bit ~~quantiser~~quantizer. When reproducing the digital
10   signal, the identical noise signal is subtracted from the recorded
signal to provide a substantially noise-free 16-bit signal.
~~Synchronisation~~ Synchronization of the noise signal and the digital
signal is achieved by regenerating an indicator signal from the
recorded signal.

15   [0003]   Present day ~~quantisation~~ quantization of signals for
recording on a recording medium, such as compact discs, is limited
to 16 bits, resulting in a maximum dynamic range of only 96 dB.
Although it is possible to use the same recording techniques for
recording digital signals with a larger word length and thus higher
20   dynamic range, such a recording would not be compatible with older
systems for replay. The method and system described in GB-A-2 293
297 improve the quality of playback of the signal by adding noise
to the signal before ~~quantising~~quantizing, but as the
~~synchronisation~~ synchronization and noise parameter data are

included in the recorded signal, identical copying of the recorded signal is possible.

SUMMARY OF THE INVENTION

5 **[0004]**   The present invention therefore seeks to provide a method and apparatus for reducing the word length of a digital signal having an increased dynamic range, while remaining backwards compatible with methods and apparatus for replaying the reduced ~~word~~ word-length signal, such as the ~~standardised~~ standardized CD-

10 signal of 16 bits. Also, it should be possible with the present invention to provide an anti-copy protection of the ~~quantised~~ quantized signal.

[0005]   The present invention provides a method according to the preamble defined above, in which the step of ~~quantising~~ quantizing

15 the intermediate signal comprises a first transfer function which is non-linear, the first transfer function being defined by non-linear device parameters. By properly choosing the noise parameters and non-linear device parameters, it is possible to obtain a reduced ~~word~~ word-length signal which may be recovered or replayed

20 using conventional means, but with a reduced quality. When n is equal to m, no reduction in bit length occurs, but the effect of the non-linear transfer device and the addition of noise remain.

[0006]   In a further embodiment, a ~~quantisation~~ quantization step of the first transfer function for small amplitudes is smaller than

25 a ~~quantisation~~ quantization step for large amplitudes. Preferably,

the gain of the first transfer function is substantially equal to one for small amplitudes, and in which the gain decreases for large amplitudes. An example of a transfer function is given by the function $M_e/D_i = c_1 \tanh(c_2 D_i + c_3)$, in which M_e is the reduced

5   word length signal, D_i is the intermediate signal and c_1, c_2, c_3 are the non-linear device parameters. The first transfer function determines the amount of distortion in the reduced ~~word~~ word-length signal. The human ear is more sensitive ~~for~~ to noise in small amplitude signals than ~~for~~ to noise in large amplitude signals.

10   This psycho-acoustic effect allows ~~to add~~ adding noise to degrade the reduced ~~word~~ word-length signal while still being discernible and audible, be it at a reduced quality level.

[0007]   In a further embodiment, the amplitude of the noise signal is at least equal to a predetermined noise value. This

15   predetermined noise value is chosen to assure that a dither effect is provided, even for large amplitude signals.

[0008]   ~~Noise~~ Noise-shaping techniques may be applied to obtain the noise signal having more preferred characteristics.

[0009]   In an even further embodiment, the reduced ~~word~~ word-

20   length signal, the non-linear device parameters and/or the noise parameters are recorded on a recording medium. As an example, the recording medium is a compact disc, and the reduced ~~word~~ word-length signal is recorded on a first channel and the non-linear device parameters and/or the noise parameters are recorded on a

25   second channel, the first channel and second channel being separate

channels. This ~~allows to provide~~enables providing a low quality

reduced ~~word~~ word-length signal, e.g.,, as a pre-view (better pre-

listen) signal. Only when the receiver also receives the non-linear

device parameters and the noise parameters, the original full

5   quality digital signal can be recovered. As the non-linear device

parameters and noise parameters are distributed over a channel

separate from the reduced ~~word~~ word-length signal, the present

method also provides an anti-copying capability of the high quality

signal.

10   **[0010]**   Also, the present method may comprise the further step of

providing a difference signal, the difference signal being equal to

the intermediate signal minus the reduced ~~word~~ word-length signal.

[0011]   The present invention also relates to a method for

recovering an output signal from a reduced ~~word~~ word-length signal

15   provided by the method according to the present invention,

comprising the steps of ~~quantising~~ quantizing the reduced ~~word~~

word-length signal having m bits to a decoded signal having n bits,

the ~~quantising~~ quantizing being defined by a second transfer

function, the second transfer function being the inverse of the

20   first transfer function. This ~~allows to recover~~enables recovering

an output signal having the original word length of the original

digital input signal, providing an output signal with a high

dynamic range.

[0012]   In a preferred embodiment, a subtraction noise signal is

25   subtracted from the decoded signal in order to provide the output

signal, the subtraction noise signal being substantially equal to the noise signal. This embodiment ~~allows to recover~~enables recovering an output signal with a high quality level, the only additional degradation of the original digital input signal being

5 formed by the ~~quantisation~~ quantization noise introduced by the non-linear ~~quantisation~~ quantization operation. By properly choosing the non-linear device parameters and noise parameters, this additional degradation may be limited to an acceptable level.

[0013] In a second aspect, the present invention relates to a

10 signal processing apparatus according to the preamble defined above, in which the ~~quantising~~ quantizing element has a non-linear transfer function, the non-linear transfer function being defined by non-linear device parameters. More preferably, the signal processing is arranged to execute the method according to the

15 present invention.

[0014] Also, the present invention relates to a signal decoding apparatus for recovering an output signal from a reduced ~~word~~ word-length signal provided by the signal processing apparatus ~~according to the present claim~~described above, comprising a second

20 ~~quantisation~~ quantization element having a second transfer function for transforming the reduced ~~word~~ word-length signal into a decoded output signal, the second transfer function being the inverse of the first transfer function.

[0015] In a preferred embodiment, the signal decoding apparatus

25 comprises a second noise source for providing a subtraction noise

signal to a subtraction element, the subtraction noise signal being substantially equal to the noise signal, the subtraction element being arranged for subtracting the subtraction noise signal from the decoded signal in order to provide the output signal.

5 [0016]   The present invention may be applied to all sorts of digital signals, representing e.g., an audio signal or a video signal.

BRIEF DESCRIPTION OF THE DRAWINGS

10 [0017]   The present invention will be described in more detail with the aid of exemplary embodiments with reference to the accompanying drawing, in which:

[0018]   ~~the figure showing~~Fig. 1 shows a block schematic diagram of ~~signal flows in the method according to~~a first embodiment of the

15 present invention; and

[0019]   Fig. 2 shows a block schematic diagram of a second embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

20 [0020]   A digital input signal D_i, having a word length of n bits (e.g., 20 bits) is ~~being~~ input to a first non-linear device (NLD) 10. The first NLD 10 has a transfer characteristic such that the word length of the digital input signal D_i is reduced from n bits to m bits for the first reduced ~~word~~ word-length signal M_e (e.g.,

25 from 20 bits to 16 bits, as in a usual CD signal). The transfer

characteristic is non-linear, e.g., the ~~quantisation~~ quantization
step for small amplitudes is larger than the ~~quantisation~~
quantization step for large amplitudes. The gain for small
amplitudes may be substantially equal to one (linear

5   characteristic), while for large amplitudes, the gain decreases. An
example for such a transfer characteristic is the following
function:

$$M_e/D_i = c_1 \tanh (c_2D_i + c_3),$$

c_1, c_2 and c_3 being predetermined NLD parameters NLD_p.

10   **[0021]**   In general, the characteristic function of the first NLD
10 should comply with the requirements, that the function should be
monotonous over the input signal range, that for zero input value,
the output value should be substantially zero (i.e., in the above
equation, $c_3 \approx 0$, and preferably $c_3 = 0$), and that the output value for

15   negative input values should be substantially equal to minus the
positive input value (i.e., $f(-x) \approx -f(x)$). Of course, the
characteristic function should also comply with the primary
objective of the first NLD 10, i.e., to reduce the word length of
the digital input signal D_i from n bits to m bits.

20   **[0022]**   Preferably, a noise signal N is added to an original
digital input signal M_i to obtain the digital input signal D_i. The
noise signal N is generated ~~utilising~~ utilizing a pseudo-random
dither-noise source 12. The noise signal N is added to the original
digital input signal M_i by adder 11, resulting in the digital input

25   signal D_i.

[0023]   The characteristic of the added noise signal may be determined by noise parameters N_p, such as the probability density function (pdf), amplitude, seed value, etc. The noise parameters N_p are chosen to affect the original digital input signal M_i at a

5   predetermined level such that a constant output signal (which is highly undesirable) is prevented. This step is also known in the art as dithering a signal. When the original digital input signal M_i is a digital data stream representing an audio signal, the added noise signal may deteriorate the audio signal, ranging from hardly

10   audible to clearly audible. To have a sufficient effect on the signal after it has passed the first NLD 10, the added noise signal should have an amplitude which is large enough to accomplish a dither effect in the signal after the first NLD 10.

[0024]   The digital input signal D_i (including the added noise

15   signal N) is input to the first NLD 10.A rather high distortion of the original digital input signal M_i by the noise signal N may still be discernible for the human ear, although with a noticeable decrease of signal quality. Moreover, by controlling the noise parameters N_p, the overall SNR may be influenced.

20   [0025]   The reduced ~~word~~ word-length signal M_e may be recorded on a recording medium 13, such as a compact disc. This compact disc 13 thus comprises the reduced word length signal M_e having an m-bit word length. For reasons of clarity, the further signal processing for recording a digital signal on a compact disc 13, such as the

25   error correction and EFM modules, have not been depicted. When, as

discussed before, m has the value 16, the compact disc 13 with the reduced ~~word~~ word-length signal M_e may be played back on a conventional 16-bit compact disc player. As the original input signal M_i has been non-linearly modified, the replayed signal will,

5   however, be more or less distorted, depending on the amount of the noise signal added by the noise source 12 and the amount of distortion introduced by the first NLD 10. Alternatively, the reduced ~~word~~ word-length signal M_e may be transmitted by means of a transmission medium, such as the Internet or a telephone line, to a

10   receiver.

[0026]   For recovery of the original input signal M_i, the reduced ~~word~~ word-length signal M_e is input into a second NLD 14. The second NLD 14 ~~has the inverse~~, having a characteristic inverse to that of the first NLD 10, ~~transforming~~ transforms the m-bit reduced

15   ~~word~~ word-length signal M_e into an n-bit decoded signal M_d. Of course, the decoded signal M_d will comprise ~~quantisation~~ quantization noise caused by the subsequent operations on the signal by the first NLD 10 and second NLD 14.

[0027]   The addition of the noise signal N to the original

20   digital input signal M_i and the subsequent non-linear operation by the first non-linear device 10 provides a reduced ~~word~~ word-length signal M_e, in which the SNR for small amplitudes is smaller than the SNR for large amplitudes. However, the second non-linear device 14 reduces the relatively large noise component for small

25   amplitudes and amplifies the relatively small noise component at

large amplitudes, thus resulting in a substantially constant SNR
over all amplitudes.

[0028]   In a preferred embodiment, the added noise signal may be
subtracted from the decoded signal M_d by a subtraction element 15,

5   providing an n-bit output signal M_o which is substantially equal to
original digital input signal M_i. For this, preferably, a second
noise source 16 (possibly identical to the noise source 12) is
used, which may generate the noise signal to be subtracted from the
decoded signal M_d using the noise parameters N_p. For a good

10   operation, the second noise signal N_2 should be ~~synchronised~~
synchronized with the reduced ~~word~~ word-length signal M_e.

[0029]   Both the NLD parameters NLD_p and the noise parameters N_p
may be fixed values. In this case, these parameters may be included
in the first NLD 10, second NLD 14, noise source 12 and second

15   noise source 16, e.g.~~.~~, by storing the parameters NLD_p, N_p in an
associated memory element (not shown).

[0030]   In a preferred alternative embodiment, the parameters
NLD_p, N_p are variable parameters, which may be transferred together
with the reduced ~~word~~ word-length signal M_e. When the reduced ~~word~~

20   word-length signal M_e is recorded on a compact disc, as discussed
above, the parameters may be stored in the sub-code of the compact
disc, but ~~also~~, alternatively, may be stored by employing a
physical change in the compact disc, such as pit-length modulation
or pit-depth modulation. The solution with the physical change

25   provides the additional benefit that a normal compact disc copy

operation will only copy the reduced ~~word~~ word-length signal M_e, and not the physically encoded parameters NLD_p, N_p. This provides a good anti-copy protection, as the reduced ~~word~~ word-length signal M_e can not be ~~recovered~~ transformed to the n-bit output signal M_o

5   without the added noise signal N.

[0031]   Of course, the parameters NLD_p, N_p and the reduced ~~word~~ word-length signal M_e may be transferred over separate channels, either physically separated channels or channels separated in the time domain. It is, e.g., possible to provide the reduced ~~word~~

10   word-length signal M_e as a preview (or better, pre-listen) signal, e.g., via the Internet. The preview signal M_e has a reduced quality (lower SNR) compared to the original digital input signal M_i, but the NLD parameters NLD_p and noise parameters N_p are chosen such that the signal is still acceptable for preview purposes. Only

15   after payment, the parameters NLD_p, N_p will be made available via a separate channel (e.g., a secure Internet connection), in order to allow recovery of the output signal M_o with high quality.

[0032]   It will be apparent to the person skilled in the art that other variants are possible, such as only either the NLD parameters

20   NLD_p or the noise parameters N_p being variable. The fixed parameters may ~~than~~ then be included in the replay equipment (buried in silicon), while the variable parameters are transferred with the reduced ~~word~~ word-length signal M_e.

[0033]   In a further embodiment, ~~noise~~ noise-shaping techniques

25   are applied when generating the noise signal N to be added to the

original digital input signal M_i, allowing, e.g., a feedback of the ~~quantisation~~ quantization error caused by the first NLD 10.

[0034]   In an even further embodiment, as shown in Fig. 2, ~~not~~ the reduced ~~word~~ word-length signal M_e is not recorded, but rather,

5   the difference $\Delta_{ie} = D_i - M_{ei}$, as formed in difference circuit 18, is recorded. For certain applications, such a coding technique may provide further advantages, such as requiring a reduced ~~word~~ word-length signal M_e to be recorded with an even lower word length.

[0035]   Thus, the present method ~~allows to record~~ enables

10   recording an original digital data signal M_i having a high dynamic range on a medium using a reduced ~~word~~ word-length signal M_e (with a lower dynamic range) and ~~to recover~~ recovering an output signal again having ~~again~~ a high dynamic range. The present method provides a backwards compatibility with older recovery equipment

15   arranged for recovering a signal with the reduced word length of M bits, although some signal degradation may occur caused by the non-linear ~~word~~ word-length reduction of the first NLD 10 and the addition of dither noise from the noise source 12. As mentioned before, copying of the recorded signal and associated parameters

20   NLD_p, N_p, e.g., on a compact disc 13, using generally available equipment may be prevented using certain modulation techniques. The present method also ~~allows to improve~~ enables improving the performance of, e.g., compact disc players by increasing the maximum dynamic range of the output signal M_O while retaining

25   backwards compatibility.

ABSTRACT~~÷~~ OF THE DISCLOSURE

~~Method~~ A method and signal processing apparatus for
reducing the number of bits of a digital input signal $(M_i)_{\llcorner}$
5 ~~comprising the steps of~~ includes adding a pseudo-random noise signal
(N_a) to the digital input signal (M_i) to obtain an intermediate
signal (D_i), the pseudo-random noise signal (N_a) being defined by
noise parameters (N_p), and ~~quantising~~ quantizing the intermediate
signal $(D_i)_{\llcorner}$ having a word length of n bits$_{\llcorner}$ to a reduced ~~word~~
10 word-length signal (M_e) having a word length of m bits, n being
larger than or equal to m. The method further ~~comprises the step~~
~~of~~ includes ~~quantising~~ quantizing the intermediate signal (D_i)
~~comprises~~ using a first transfer function which is non-linear, the
first transfer function being defined by non-linear device
15 parameters (NLD_p). ~~Also, the present invention relates to a method~~
~~and signal decoding apparatus for recovering an output signal (M_e)~~
~~from a reduced word length signal (M_e) provided by the method~~
~~according to the invention.~~

20 ~~(Fig. 1)~~